1. Purpose of Experiments
Include immediate goal of the experiments, scientific importance and/or programmatic relevance. Refer to any relevant program milestones.

The experiments aim to determine the input power requirements to maintain a high confinement H-mode in a range of conditions and compare these to those for access to the H-mode regime in Alcator C-mod. The role of the magnitude of plasma radiation and its spatial distribution on the power requirements for stationary high confinement H-mode will be assessed by injection of impurities with various Z. Understanding quantitatively these requirements is crucial for the planning of ITER operations during the non-active phase as well as for the determination of the total level of additional heating that needs to be available for the achievement of ITER $Q_{DT}=10$ goal. These issues have been highlighted as a high priority issue by the ITPA Pedestal and Transport and Confinement groups. Given the different characteristics of the H-mode regime in various devices and the lack of the systematic studies on these issues, it is necessary to perform experiments in individual devices before meaningful multi-machine experiments can be carried out.

2. Background
Discuss Physics Basis of the proposed research. Prior results at Alcator or elsewhere, and any related work being carried out separately.

The power requirements for access to H-mode regime and their dependence on global plasma parameters in terms of plasma density, toroidal field have been subject of extensive experimental studies given their importance for fusion performance in ITER. On the contrary, the required power to maintain a high confinement H-mode and its relation to the H-mode threshold power and its dependence on plasma conditions are much more poorly known and have been mainly investigated at JET [Sartori 2004]. The importance of these issues both for ITER non-active operation and for the required available power to achieve inductive high fusion gain regimes has been recently highlighted. This reconsideration has been driven by the re-evaluation of the H-mode threshold power for ITER [Martin 2008] and the new ITER experimental strategy that
relies on the development of Type I ELM control methods (and thus need of a high confinement H-mode) during the non-active operational phase.

The present estimates of the edge power flow required to access and maintain a stationary high confinement H-mode indicate that the minimum required edge power flow is only marginally lower than that expected for plasmas in ITER. This is valid not only for the available heating power during the non-active phase but also for the conditions with alpha-dominated plasmas for $Q_{DT}=10$ operation. Thus it is necessary to study in detail the edge/pedestal and confinement properties of plasmas with input powers close to the H-mode threshold power as well as to assess the influence of plasma radiation and its spatial distribution on determining the required level of additional heating for high confinement H-modes in these conditions.

Most of the existing results in this field come from JET where high current operation with stationary high confinement H-modes is limited by the installed level of additional heating. Operation with insufficient power above the H-mode threshold leads to oscillatory plasma behaviour with phases of high confinement Type I ELM My H-mode and low confinement Type III ELM My H-modes or L-mode. The margin to the expected H-mode threshold power to maintain stationary Type I ELM My H-mode is seen to depend of global plasma parameters such as plasma triangularity. It is unknown if the observations from JET are representative of what could be expected in ITER or are associated with JET specific issues such as size of ELM-caused crashes of pedestal parameters in these conditions, etc. Experimental investigation of these processes in other devices, such as C-mod, which have very different plasma behaviour from JET but typically operate close to the L-H transition threshold, would add an important insight to untangle the key physics processes involved and possibly provide an initial evaluation of their relevance to ITER.

3. Approach

Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

The experiment consists on the establishment of the power requirements for H-mode access at 2 (or, if possible 3) values of the L-mode target (and stationary) H-mode densities and the determination of the pedestal plasma characteristics and plasma confinement properties in the EDA and ELM My H-mode regime in Alcator C-mod for various levels of additional heating above the required power for H-mode access. For a selected power/density level in EDA and ELM My H-mode regimes, an assessment of the effect of radiation level and its spatial distribution on H-mode characteristics will be carried out. This will be performed by injecting impurities of various Z and comparing these discharges with unseeded plasmas with similar bulk plasma power outflow.

In order to determine the power requirements with respect to H-mode access, the H-mode threshold will also be determined directly (i.e. not by a scaling) for L-mode discharges with target densities similar to those obtained in stationary H-modes (assuming that these densities are achievable in L-mode). The three values of target L-mode densities will be defined as: the middle value should be at the density for minimum H-mode threshold, the highest one well above that (while maintaining H-mode access) and the lowest target density should be slightly lower than the minimum density for minimum H-mode threshold. The choice of plasma parameters is based on the existing C-mod database and optimized to achieve the highest level of ICRH heating both for EDA and ELM My H-mode
experiments. The plasma current will be 0.8 MA and the toroidal field 5.4 T allowing a maximum power to be injected by ICRH (80 MHz) of ~ 5-6 MW both for EDA and ELMy H-mode conditions.

The unseeded discharges will have a power ramp to the expected level of the H-mode threshold power for the target density selected (3 values, if possible) allowing the plasma to enter the H-mode. This will be followed by a fast increase of the power to its flat top level to document the effect of the power on H-mode behaviour. It is expected to perform three power levels (low, medium, high) per target density both in EDA and ELMy H-mode conditions, with the low value being the lowest priority one.

For those conditions in which the stationary H-mode density can also be achieved in L-mode, some dedicated shots with power ramps will be performed in order to determine the H-mode threshold in these conditions and for checking against the present scalings.

For the highest power/medium density conditions, impurities of various Z (Ar, Ne, N₂) will be puffed into the plasma (possibly from the divertor) to various puffing levels to document the effect of plasma radiation and its spatial distribution on H-mode characteristics. Ideally, two levels of bulk plasma radiation per impurity species should be documented. The edge power outflow in these seeded shots will be matched in the unseeded experiments by adjusting the level of additional heating in the low and medium input power conditions.

Besides standard bulk plasma measurements, key measurements to obtain in this experiment are pedestal, edge and divertor plasma density and temperatures, core and edge plasma rotation, edge temperature and density, divertor plasma density and temperature measurements, turbulence and other MHD activity, radiated power, Zₘₑ, etc.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:
- Toroidal Field: 5.4 T
- Plasma Current: 0.8 MA
- Working Gas Species: Deuterium
- Target density: 10 x 10¹⁹ m⁻² – 20 x 10¹⁹ m⁻³

Equilibrium configuration (if possible, refer to database equilibria): Standard EDA for optimum ICRH and ELMy H-mode (δ_lower > 0.75, δ_upper ~0.15)

4.2 Auxiliary Systems

- RF Power, pulse length, phasing: ICRF at 80 MHz up to 5 MW
- Pellet Injection (species): None
- Impurity blow-off injection: None
- Boronization: Required
- Diagnostic Neutral Beam: Yes, if available
- Special gas puffing: Impurity puffing (Ar, Ne, N₂ from divertor)
- Non-axisymmetric Coils (Connections, Current): Standard configuration
- Other: Cryopump for density and impurity control

4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

Core and edge Thomson for temperature and density profiles. ECE for both pedestal and core temperature profiles. HIREX for ion temperature and rotation profiles. CXRS with DNB for ion
temperature measurements, if available. Bolometry for radiation profile measurements. Visible Bremsstrahlung for $Z_{\text{eff}}$ measurements. Fast magnetic pick-up coils, PCI, and Reflectometry for fluctuation measurements. Fast scanning probes for SOL measurements for low $P_{\text{SOL}}$ conditions, if possible. Divertor probes and IR (if available) for divertor characterization.

5. Experimental Plan

Both sections must be filled in.

5.1 Run sequence Plan

Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period – 10 hours maximum – etc.

~ 1.5-2.0 run days are required to do the complete experiment.

5.2 Shot sequence plan

For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

A. EDA Configuration (seeded plasmas)

A.1. L-mode target density $<n_e> = 1.2 \times 10^{19} \text{ m}^{-3}$. $P_{\text{ICRH}} = 4.5 \text{ MW}$. Injection of Ar to achieve $P_{\text{rad core}} \sim 1 \text{ MW}$.

A.2. L-mode target density $<n_e> = 1.2 \times 10^{19} \text{ m}^{-3}$. $P_{\text{ICRH}} = 4.5 \text{ MW}$. Injection of Ar to achieve $P_{\text{rad core}} \sim 2 \text{ MW}$.

A.3. L-mode target density $<n_e> = 1.2 \times 10^{19} \text{ m}^{-3}$. $P_{\text{ICRH}} = 4.5 \text{ MW}$. Injection of Ne to achieve $P_{\text{rad core}} \sim 1 \text{ MW}$.

A.4. L-mode target density $<n_e> = 1.2 \times 10^{19} \text{ m}^{-3}$. $P_{\text{ICRH}} = 4.5 \text{ MW}$. Injection of Ne to achieve $P_{\text{rad core}} \sim 2 \text{ MW}$.

A.5. L-mode target density $<n_e> = 1.2 \times 10^{19} \text{ m}^{-3}$. $P_{\text{ICRH}} = 4.5 \text{ MW}$. Injection of $N_2$ to achieve $P_{\text{rad core}} \sim 1 \text{ MW}$.

A.6. L-mode target density $<n_e> = 1.2 \times 10^{19} \text{ m}^{-3}$. $P_{\text{ICRH}} = 4.5 \text{ MW}$. Injection of $N_2$ to achieve $P_{\text{rad core}} \sim 2 \text{ MW}$.

The power waveform should be optimised to facilitate the achievement of the required radiation during the power/density flat top and minimise disruptions by radiative plasma collapses.

B. ELMy H-mode Configuration (seeded plasmas)

The target density and radiated power levels for ELMy H-modes are assumed to be the same as EDA plasmas above. Given the more restricted density/power ranges in which ELMy H-modes are found to exist in C-mod, the values of target density and radiated powers may need to be adjusted.

B.1. L-mode target density $<n_e> = 1.2 \times 10^{19} \text{ m}^{-3}$. $P_{\text{ICRH}} = 4.5 \text{ MW}$. Injection of Ar to achieve $P_{\text{rad core}} \sim 1 \text{ MW}$.
B.2. L-mode target density \( n_e = 12 \times 10^{19} \text{ m}^{-3} \). \( P_{ICRH} = 4.5 \text{ MW} \). Injection of Ar to achieve \( P_{rad}^{core} \sim 2 \text{ MW} \).

B.3. L-mode target density \( n_e = 12 \times 10^{19} \text{ m}^{-3} \). \( P_{ICRH} = 4.5 \text{ MW} \). Injection of Ne to achieve \( P_{rad}^{core} \sim 1 \text{ MW} \).

B.4. L-mode target density \( n_e = 12 \times 10^{19} \text{ m}^{-3} \). \( P_{ICRH} = 4.5 \text{ MW} \). Injection of Ne to achieve \( P_{rad}^{core} \sim 2 \text{ MW} \).

B.5. L-mode target density \( n_e = 12 \times 10^{19} \text{ m}^{-3} \). \( P_{ICRH} = 4.5 \text{ MW} \). Injection of \( \text{N}_2 \) to achieve \( P_{rad}^{core} \sim 1 \text{ MW} \).

B.6. L-mode target density \( n_e = 12 \times 10^{19} \text{ m}^{-3} \). \( P_{ICRH} = 4.5 \text{ MW} \). Injection of \( \text{N}_2 \) to achieve \( P_{rad}^{core} \sim 2 \text{ MW} \).

C. EDA Configuration (unseeded plasmas)

C.1. L-mode target density \( n_e = 12 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 1.5 \text{ MW} \) to determine H-mode threshold followed by step to achieve \( P_{ICRH} - P_{rad}^{core} = 2.5 \text{ MW} \) (i.e. as A.2, A.4, A.6).

C.2. L-mode target density \( n_e = 12 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 1.5 \text{ MW} \) to determine H-mode threshold followed by step to achieve \( P_{ICRH} - P_{rad}^{core} = 3.5 \text{ MW} \) (i.e. as A.1, A.3, A.5).

C.3. L-mode target density \( n_e = 12 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 1.5 \text{ MW} \) to determine H-mode threshold followed by step to \( P_{ICRH} = 5.0 \text{ MW} \) (if not done already in C.2).

C.4. L-mode target density \( n_e = 20 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 2.0 \text{ MW} \) to determine H-mode threshold followed by step to \( P_{ICRH} = 3.0 \text{ MW} \).

C.5. L-mode target density \( n_e = 20 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 2.0 \text{ MW} \) to determine H-mode threshold followed by step to \( P_{ICRH} = 4.0 \text{ MW} \).

C.6. L-mode target density \( n_e = 20 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 2.0 \text{ MW} \) to determine H-mode threshold followed by step to \( P_{ICRH} = 5.0 \text{ MW} \).

C.7. L-mode target density \( n_e = 24 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 3.5 \text{ MW} \) to determine H-mode threshold.

With lower priority, the low target density point should be explored:

C.8. L-mode target density \( n_e = 10 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 3.0 \text{ MW} \) to determine H-mode threshold followed by step to \( P_{ICRH} = 4.0 \text{ MW} \).

C.9. L-mode target density \( n_e = 10 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 3.0 \text{ MW} \) to determine H-mode threshold followed by step to \( P_{ICRH} = 4.5 \text{ MW} \).

C.10. L-mode target density \( n_e = 10 \times 10^{19} \text{ m}^{-3} \). ICRH power ramp to \( \sim 3.0 \text{ MW} \) to determine H-mode threshold followed by step to \( P_{ICRH} = 5.0 \text{ MW} \).
The reason for the low priority of C.8-C.10 is that it is very likely that the follow-up H-mode is not an EDA but ELM-free, which is not useful for the purpose of the experiment.

In the above plan it is assumed that the plasma density in going from L-mode to EDA H-mode will approximately double so that the H-mode threshold data obtained in (C.4-C.6) provides a reference for H-mode conditions in (C.8-C.10). The value for plasma densities are chosen on the basis that the minimum threshold is achieved at ~ $12 \times 10^{19} \text{ m}^{-3}$ and $P_{L-H} \sim 1.5 \text{ MW}$. The low density point (C.8-C.10) is chosen so that it is lower than this minimum threshold density but high enough as to allow a meaningful power scan in H-mode conditions (i.e., the H-mode threshold in C.8-C.10 should not be much larger than 2.5 MW).

D. ELMy H-mode Configuration (unseeded plasmas)

D.1. L-mode target density $<n_e> = 12 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 1.5 MW to determine H-mode threshold followed by step to achieve $P_{ICRH} - P_{rad \text{ core}} = 2.5 \text{ MW}$ (i.e. as B.2, B.4, B.6).

D.2. L-mode target density $<n_e> = 12 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 1.5 MW to determine H-mode threshold followed by step to achieve $P_{ICRH} - P_{rad \text{ core}} = 3.5 \text{ MW}$ (i.e. as B.1, B.3, B.5).

D.3. L-mode target density $<n_e> = 12 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 1.5 MW to determine H-mode threshold followed by step to $P_{ICRH} = 5.0 \text{ MW}$ (if not done in D.2).

D.4. L-mode target density $<n_e> = 20 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 2.0 MW to determine H-mode threshold followed by step to $P_{ICRH} = 3.0 \text{ MW}$.

D.5. L-mode target density $<n_e> = 20 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 2.0 MW to determine H-mode threshold followed by step to $P_{ICRH} = 4.0 \text{ MW}$.

D.6. L-mode target density $<n_e> = 20 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 2.0 MW to determine H-mode threshold followed by step to $P_{ICRH} = 5.0 \text{ MW}$.

D.7. L-mode target density $<n_e> = 24 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 3.5 MW to determine H-mode threshold.

With lower priority the low target density point should be explored:

D.8. L-mode target density $<n_e> = 10 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 3.0 MW to determine H-mode threshold followed by step to $P_{ICRH} = 4.0 \text{ MW}$.

D.9. L-mode target density $<n_e> = 10 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 3.0 MW to determine H-mode threshold followed by step to $P_{ICRH} = 4.5 \text{ MW}$.

D.10. L-mode target density $<n_e> = 10 \times 10^{19} \text{ m}^{-3}$. ICRH power ramp to ~ 3.0 MW to determine H-mode threshold followed by step to $P_{ICRH} = 5.0 \text{ MW}$.

The reason for the low priority of D.8-D.10 is that it is possible that power requirements are too high and that an EDA comparison discharge is unlikely to exit in these conditions.
In the above plan it is assumed that the plasma density in going from L-mode to ELMy H-mode will approximately double so that the H-mode threshold data obtained in (D.4-D.6) provides a reference for H-mode conditions in (D.8-D.10). The value for plasma densities are chosen on the basis that the minimum threshold is achieved at $12 \times 10^{19} \text{m}^{-3}$ and $P_{L-H} \sim 1.5 \text{ MW})$. The low density point (D.8-D.10) is chosen so that it is lower than this minimum threshold density but high enough as to allow a meaningful power scan in H-mode conditions (i.e., the H-mode threshold in D.8-D.10 should not be much larger than 2.5 MW).

6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

This experiment will document the pedestal plasma behaviour in H-mode close to the L-H transition and its influence on plasma confinement. The comparison between EDA and ELMy H-mode would allow determining if effects near the L-H transition seen in other experimental devices are associated with H-mode barrier properties or with the ELM size and dynamics in these conditions. Similarly the role of bulk plasma radiation and its spatial distribution will be assessed by comparing different impurities with constant edge power flux for seeded and unseeded plasmas.

The consequences for predictions regarding the behaviour and performance of ITER plasmas depend on the outcome of the experiments and can be summarized as follows:

a) The need for excess power above the L-H threshold to get high confinement H-modes will be documented in C-mod providing additional information besides that from JET and will show whether the JET findings (adopted for ITER prediction) are of general application or not. This will also indicate if there are or not some basic common barrier physics processes near the L-H threshold to all devices whose physics need to be studied in detail to predict the behaviour of ITER plasmas in these conditions.

b) The role of ELM dynamics in affecting the pedestal plasma and its influence in driving the plasma to lower confinement conditions for powers close to the L-H transition will be demonstrated by the comparison of EDA and ELMy H-mode results. This may show that under conditions required in ITER (i.e. controlled ELM losses), similar to EDA, the pedestal plasma pressure and energy confinement can be built up gradually without the oscillating behaviour found at JET for ELMy H-modes, which has clear implication for both the active and non-active phase of ITER operation.

c) The role of radiation and its spatial distribution on the power required to maintain high confinement H-modes will be assessed. This will indicate whether the assumption of subtracting all radiation in the bulk plasma to estimate the margin above H-mode threshold in ITER $Q_{DT}=10$ operation is justified or not regarding both core and edge radiation.

7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.